The impact of Stephen Hales on medicine

I B Smith MD FRCS *Cornerways, Anslow Lane, Rolleston-on-Dove, Staffordshire DE13 9DS*

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Introduction

I was introduced to Stephen Hales by my home-guard commander in Cambridge, Captain Clark-Kennedy[1], at the beginning of the Second World War. This paper about Hales' contributions to medicine follows from reading much of what Hales wrote as well as the scholarly book by Allan and Schofield[2]. Although some doctors know how Hales measured the blood pressure of his famous mare, many remain unaware how much else he contributed to medicine, plant physiology and pneumatic chemistry. Born in Kent in 1677 into a Norman family with distinguished forebears, he grew up in the discipline of his grandfather Sir Thomas Hales' home near Canterbury. Although his parents and grandfather died before he was 17, he had the advantage of three good school masters in Kensington, Orpington and Murston and went up to Bene't College, Cambridge in 1696. Four years later he came twenty second of 127 BA graduates. In 1703 he was ordained deacon at Bugden and took up his fellowship at Bene't[1,2].

During the 6 years 1703-1709, without any college or university responsibility and while waiting for a suitable living, Hales developed his scientific interests and habit of experiment. Help and influences in this direction included his private means and family contacts, his close friendship in college with William Stukely. They also included the teachings in Cambridge of several innovative and distinguished scientists such as Newton, Vigani, James Keill, Cotes and Freind as well as Pitcairne of Edinburgh: most of them seeking to explain natural phenomena in physical terms[2] (pp 10-19),[3]. Hales later wrote:

> . . . the most likely way, therefore, to get any insight into the nature of those parts of Creation which seem to come within our observation must . . . be to number, weigh and measure[4] (p 1).

Medical experiments

Hales's early experiments concerned animal blood-pressure. This was in response to his doubts about a current 'conjecture' that the force of blood entering muscles was the cause of their contracting[5] (p 62). As Hales had already noted the minute size of muscle capillaries and the slow movement of their corpuscles, he just wanted to test this hypothesis by finding what the 'force of blood' (blood pressure (BP)) actually was. This was typical of his usual approach:

> It is by . . . Conjectures that I have been led on, Step by Step, thro' this long and laborious Series of Experiments; in any of which I did not certainly know what the Event would be, till I had made the Trial, which Trial often led on to more Conjectures and farther Experiment . . . In which method we may be continually making further Advances in the knowledge of Nature in proportion to the Number of Observations which we have[5] (p xv).

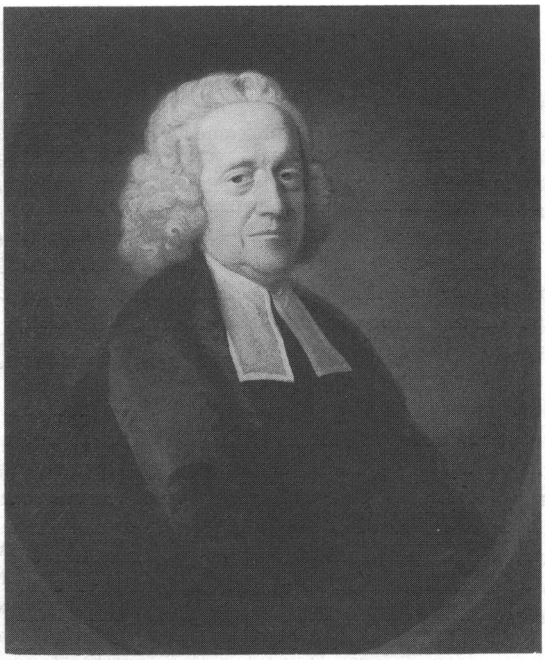

Figure 1. Stephen Hales, 1759. (By courtesy of National Portrait Gallery, London)

Not only were his conclusions limited to what the facts allowed and his progress logical; his methods and materials were always clearly defined.

Blood pressure and circulation

> As the animal Fluids move by Hydraulick and Hydrostatical Laws, so have I here made enquiry into the Nature of their Motions[5] (p xvii).

In 1707 Hales started to measure pressure in the leg and neck vessels of dogs, which were easier than capillaries. He was certainly the first to make such simple direct measurements using both terminal and lateral cannulas and his results were much closer to actual values than anything previously. But these experiments had two prolonged interruptions, when he moved to Teddington and when concentrating on plants and air. Later he was motivated to continue them by the enthusiastic response given to his *Vegetable Staticks*[2] (p 48).

He completed a wide range of tests in different animals and made a number of original findings, comments and suggestions which are now accepted as common knowledge. For instance:

> In the larger horse and ox the BP is higher and the pulse slower than in the smaller sheep and dog[5] (pp 42-4).

> BP is increased during systole, straining and movement[5] (pp 10, 33).
> With blood loss the pulse quickens and weakens as the BP falls[5] (p 12).

Halting the loss and resting the animal may allow the BP to rise[5] (p 9).
Horses died when the BP fell below 2 ft of blood[5] (p 16).
Venous pressure is much lower than arterial and lowest in the vena cava[5] (p 14).
As systemic must equal pulmonary output, a higher caval pressure will increase ventricular input and output and raise arterial BP[5] (pp 65, 79; NB *Starling's Law of 1918*).
Diastole lasts twice as long as systole[5] (p 26).
The nearer to the heart, the more during systole does the blood accelerate and the artery dilate, thus producing a steady flow and low pressure in capillaries[5] (pp 23-7, 46).
Arterial BP is influenced by the ratio of ventricular output to what can get passed the capillaries[5] (p 55).
Lung capillaries offer less resistance than systemic[5] (pp 62-73).
Warmth dilates and cold contracts arterioles and capillaries[5] (p 127).
The state of... blood vessels... are... continually varying from divers causes... so as probably never to be the same for any two minutes[5] (p 136).
Tis probable that such things as constringe the Vessels... do also proportionably increase the Force of the arterial Blood and thereby invigorate the Animal[5] (p 136).

In spite of the detail and originality of this work, it ended after the appearance of *Haemastaticks* in 1733. Perhaps it was his age of 55, perhaps his guilt about vivisection[6], or simply the transfer of his energy to more philanthropic work. But he certainly left us these original data and ideas.

Respiratory system

Hales' first recorded experiment was to make with Stukely a cast of a dog's bronchial tree. First they distended and dried the lungs with hot air repeatedly blown down the trachea through a very hot gun barrel, then they poured in moulten lead by the same method[7].

He made an original and early measurement of water-loss from respiration: 17 grains during 50 breaths in 2½ min[5] (pp 324-9) equivalent to about 0.6 l/day. However his attempt to calculate the heat lost by ventilation was less satisfactory[5] (p 98).

Concerning the function of the lungs, Hales thought that blood became red because it was agitated by its rapid passage through[5] (p 105) as when agitated in a glass vessel[5] (p 95). However, he added, 'Tis probable that the blood in the lungs may receive some important influence from the Air' implying that some component of the 'elastic' air became 'fixed' in the blood[5] (p 105). He also suggested that when a chest wound was being closed the patient should cough hard to empty the pleura, expand the lung and improve breathing[5] (p 80).

Urinary stones

Hales' early tests on claculi were to see if, just like plant and animal tissues, they would release their 'fixed air' as free 'elastic air' when heated in retorts: and so they did[4] (pp 193-9). His later searches for a good solvent for stones were aimed at relief for the many who then suffered. He was also one of the parliamentary trustees investigating Joanna Stephens' famous lithontryptic medicine.

Although Hales' findings were limited by current chemical knowledge, he was actually the first to attempt any scientific analysis of stones. However, his demonstrations that hard stones were insoluble and soft stones less so were not original and his initial support for Joanna Stephens' medicine[8] was later withdrawn[9]. But during this work he produced two useful inventions and some important advice. First:

Thinking that it might possibly be of use in Experiments of this kind to have a continuous Flow of Liquor in and out of the Bladder, I directed an ingenious Artist to make me a double Catheter and Thro' this instrument... after four hours and a half there ran in and out (of a bitch's bladder) about three Gallons . . . without the least Harm or Inconvenience to the Bitch[5] (p 212).

This is the first description of a technique which 260 years later is now used extensively by urologists. Secondly:

I suspect that the principal Cause of... the Growth of Gravel in the Kidnies is owing to the horizontal Posture... when we lay in Bed[5] (p 228).

He then describes how the low position of the calyces causes stagnation of urine, as gravity delays its passage thence into and along the ureters.

The Progress of Urine being... retarded, it has more time to deposit its Tartar in those small Ducts in the Papillae where the first minute Beginnings of Gravel are formed.

After such accurate description of the pathology of recumbency stones, little bettered today, he then explains how turning drains the calyces well:

... for the same Reason, it must needs be advisable to take care to lay alternatively sometimes on one Side and sometimes on the other[5] (pp 228-30).

Sadly, this important advice was never implemented effectively in this country until Guttmann's insistence 210 years later.

Thirdly, to enable men with a stone impacted in the urethra to avoid surgery Hales made an instrument for simple extraction:

I cut off the lower end of a strait *Catheter* which made it a proper *Cannula* for a Stillet or *Forceps* to pass thro'; the lower end of the *Forceps* was divided into two Springs like Tweezers whose Ends were turned a little inwards; these Springs were made of such a Degree of Tenderness and Pliancy as not to bear too hard against the Sides of the *Urethra* by their dilatation.
When the Instrument is used the Springs are drawn up within the *Cannula*; which being passed into the *Urethra* as far as to the Stone, the *Cannula* must then be drawn back so far as to give room for the *Forceps* to dilate; which dilated *Forceps* being then thrust down a little further so as to embrace the Stone, then the *Cannula* must again be slid down to make the *Forceps* fast hold of the Stone so as to draw it out.
I sent this instrument to *Mr Ranby* to have his Opinion of it; who tells me upon repeated Tryals he found it extracts these Stones with great Ease and Readiness; and that it is so well approved by other Surgeons, that many of them make use of it[5] (p 251).

Apart from Benjamin Gooch's favourable comment[10], I can find no reference to this instrument during the next 80 years (120 for the British including Astley Cooper)[11-13]. After 1827 'Hunter's forceps' were often used for stones[11-15]. However, these were originally designed to apply caustic to urethral strictures[16]; Hunter does not record their use for stones[17] and Coulson, the French and Germans all attribute to Hales the idea behind such use. Although Coulson also refers to several earlier extractors[13], these were larger, more cumbersome and usually used during lithotomy. Apart from the lithotrites of 1825 onwards, the first big improvement of Hale's extractor was by Council 193 years later.

Community medicine

Hales knew that exhaled air was 'vitiated' after trying to rebreathe the same air for more than 2½ min and measuring its decrease in volume and increase in temperature and humidity[5] (p 323). He also knew of the high mortality wherever people were crowded together without ventilation. So at the age of 63 he designed his ventilators, describing them to friends, then to the Royal Society in 1741 and 2 years later in his 160-page *Description of ventilators*. This detailed their different sizes, types, mechanisms and numerous potential uses with 11 helpful diagrams. Amongst the smaller models was his 'RESPIRATOR' which, with his valves plus a suitable intake-tube from fresh air, would have allowed someone to breathe and work safely in toxic air, for which it was designed. He used this word respirator 49 years before any other use recorded in the *Oxford Dictionary*, yet his original meaning and function stay the same today. Although Johnson's dictionary defined ventilator as 'An instrument contrived by Dr Hale' and Hales described his to the Royal Society before Sutton, both Sutton and Treiwald (in Sweden) each produced their own machines. However, Hales' philanthropy made him publicize his more vigorously with 23 various papers culminating in his eighty-first year (1758) with *A treatise on ventilators*.

They were, at first, cumbersome and operated manually but were later driven by windmills and proved effective. Their early common use was to dry grain for preservation. But their fame is based on the number of lives saved in ships, hospitals and gaols. Early resistance by the Admiralty was bypassed by installing them on ships taking slaves and prisoners to America. The results were impressive: two Atlantic crossings together took 575 men without any death[18]. At Newgate Prison, London, where Sir John Pringle secured their installation, the annual death rate was reduced by over 100 and at the Savoy prison from 50-100 to only one[19]. They also helped miners to continue working below.

Hales knew how much suffering was caused by alcohol and spent much of his last 27 years trying to prevent it. His anonymous *Friendly admonition to the drinkers of brandy* first appeared in 1734 with a sixth edition in 1807. Although this was published for the Society for the Promotion of Christian Knowledge with a message much more moral than medical, yet it clearly lists all the medical complications of alcoholism such as addiction, lack of will to cure, bad prognosis, sacrifice of food and welfare for drink, ill fetuses, alcoholic children, liver damage, jaundice, dropsy and fatal acute poisoning. However, his activity was also pragmatic: by lobbying and further writing he was largely responsible for Sir Joseph Jekyll's Gin Bill of 1736 aimed at reducing private distilling by taxation[1] (p 122).

His interest in preventive medicine also made him, as a Governor, recommend that the Middlesex County Hospital for smallpox, increase its use of smallpox inoculation. He pointed out that the County smallpox deaths had recently increased from an annual average of 1990 up to 3236; whereas, of the mere 182 who had been inoculated, only two had died[20].

For his parishioners in Teddington, Middlesex, he planned and supervised three improvements of their water supply[1] (p 47),[2] (p 152). For those in Farringdon, Hampshire at 81 he carefully painted white their path-side posts to prevent accidents at night[21]. Hales also preferred wholemeal bread and during the national shortages of 1756-1758 he served on a Royal Society of Arts committee to judge and reward the best hand mill available for the poor[2] (pp 105, 166).

Although Campbell's 'he was the means . . . of saving . . . more lives by his ventilators alone, than (other doctors) have . . . destroyed by their quackeries' may exaggerate[2] (p 172), Hales was undoubtedly an early, vigorous and effective pioneer of public health[3] (p 44).

Bones

As young bones growing differ from young plants and trees by needing an end strong enough for a joint, Hales wanted to find out how their growths differed. So 'with a sharp pointed Iron at half an inch distance I pierced two small holes through . . . the middle . . . of the shin bone' of a half grown chick. Two months later autopsy showed that the gap between these marks was exactly the same, though the bone was an inch longer:

> which growth was mostly at the upper end . . . where a wonderful provision is made for its Growth at the joining of the head to the shank called the Symphysis[4] (p 338).

Hunter, so often credited with the originality of this finding, was then one year old and did not reveal the results of his own tests until his lectures 45 years later[22].

Suspecting weakness at this growing symphysis, Hales measured its strength in the 'instep bone' of a young calf. After removing the overlying periostium and ligaments and anchoring the head with a pin just as orthopaedic surgeons do today, he found that it withstood 100 lbs traction but came off with 119 lbs. However, with the periostium intact it withstood 500[5] (p 171).

Nerves

Having concluded that the pressure of blood in muscle capillaries was too weak to cause muscle contractions, Hales considered that they must be the result of some 'more vigorous and active Energy whose Force is regulated by the Nerves'. Knowing of Gray's demonstration that 'electrical virtues' can be conducted along the surface of animal fibres, Hales postulated that 'electrical powers' might be conducted along nerves[5] (p 58) the first physiologist ever to do so.

Soon after that he discovered that a frog decapitated for 36 h would move its leg when its foot was touched but that such a response was absent after destruction of the spinal cord. Surprisingly, he did not thereby persuade those concerned with the causation of muscle contraction that it was due to muscle's inherent 'property of irritability', for Whytt, to whom he wrote, still preferred to attribute it to 'sensibility' ie 'the active power of an immaterial cause'[23]. Hales' data came 80 years before the word and concept of Reflex were first introduced and defined by Marshall Hall in 1833.

Croonian lecture

Hales often felt that the more detail he could discover about the structure and physiology of plants, animals and men, the more he was compelled to worship God, who had designed and created all. So, when he was invited to give the annual sermon 'according to the Institution of Dr Croun and his widow the Lady Sadlier' to The Royal College of Physicians of London at St Mary-le-Bow on Sunday 21 September 1751, his text 'The wisdom and goodness of God in the formation of man' was no surprise.

Although Hales' reputation as the leading British scientist of the eighteenth century rests more on his founding of plant physiology and pneumatic chemistry[2] (p 139)[3], he did make the contributions to human physiology, anatomy and pathology outlined here. If his various suggestions about management had been implemented sooner, the practice of medicine would have been much improved.

However, surely he is unique in combining such scientific eminence with so much humility, spiritual devotion and service to mankind[1,2].

How well did science and religion agree in this man of sound understanding[2] (p 172).

Yet was his humility so prevalent that he did not disdain the lowest offices provided they tended to the good of his fellow creatures[21].

These words from John Wesley and Gilbert White best summarize Hales' qualities.

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